FUEL SYSTEM

COMBUSTION AND FLAME

Prof. Dr. Eng. Medhat A. MOHAMMED Elkelawy

medhat_abo@yahoo.com

medhatelkelawy@f-eng.tanta.edu.eg

Combustible substances :-

Substances which burn in air to produce heat and light are called combustible substances.

Eg : wood, coal, charcoal, kerosene, petrol, diesel, liquefied petroleum gas (LPG), compressed natural gas (CNG) etc.

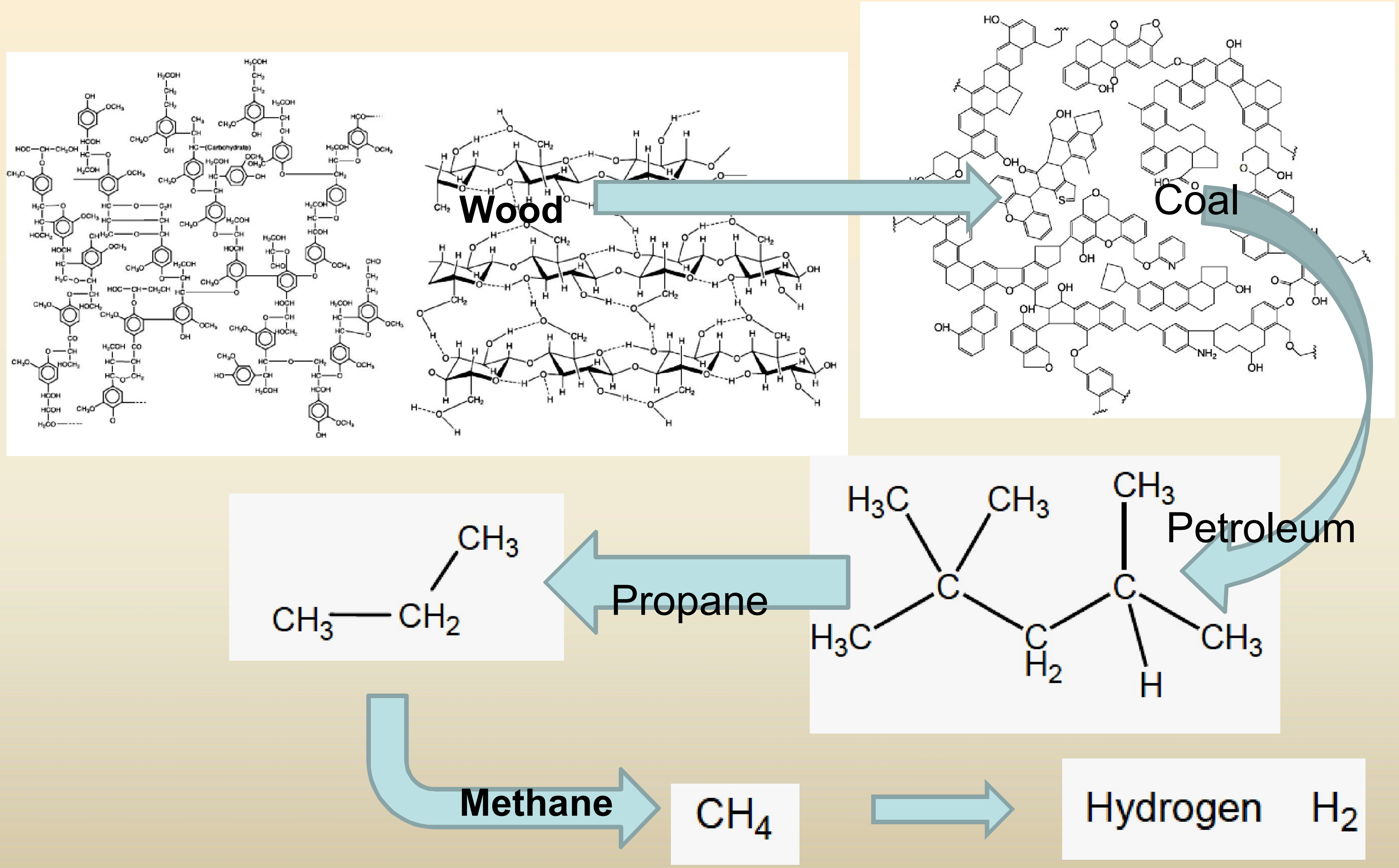
Wood

Coal

LPG

Kerosene

History of fuels usage has consistently moved in the direction of a cleaner fuel: wood → coal → petroleum → propane → methane and finally Hydrogen (fuel cell technology)



Wood

Coal

Petroleum

Propane

Methane

CH_4

Hydrogen H_2

Characteristics of a good fuel :-

The main characteristics of a good fuel are :-

- Is readily available.
- Is cheap.
- Is easy to store and transport.
- Burns at a moderate rate.
- Produces a large amount of heat.
- Does not contain any undesirable substances.
- Does not cause pollution.

The 3 Conditions for Combustion :-

The following three conditions must be fulfilled before something will burn.

- ☐ **There has to be something flammable.**

There must be some kind of "fuel," such as wood, a candle, charcoal, natural gas, petroleum or coal.

- ☐ **It has to be at the right temperature to ignite.**

The fuel must be at or above a certain temperature. The temperature at which something will ignite is called its "ignition point.

- ☐ **It has to be mixed with some fresh air (oxygen).**

Even fuel won't burn unless oxygen is present. For something to continue burning, an abundant supply of fresh air is required.

Combustion of fuels

- **_Gaseous fuels_** are generally easier to burn, handle, and control than liquid or solid fuels.
- Molecular mixing of a gaseous fuel with oxygen need not wait for vaporization or mass transport within a solid.
- Burning rates are limited only by mixing rates and the kinetics of the combustion reactions; therefore, combustion can be compact and intense.
- Reaction times as short as 0.001 sec

Combustion of fuels

- ***Combustion stability*** means that a flame lights easily and then burns steadily and reliably after the pilot (or direct spark) is programmed off.
- Combustion stability depends on **burner geometry**, plus **air and fuel flow controls** that maintain the point(s) of flame initiation:

(1) Above the fuel's minimum ignition temperature,

(2) Within the fuel's flammability limits, and

(3)With feed speed equal to flame speed—throughout the burner's full range of firing rates and conditions.

Combustion of fuels

- ***Liquid fuels*** are usually not as easily burned, handled, or controlled as gaseous fuels. Mixing with oxygen can occur only after the liquid fuel is evaporated; therefore, burning rates are limited by vaporization rates.
- One of the most critical properties is **viscosity, which hinders good atomization**, since atomization or the creation of small droplets is the primary method for enhancing vaporization.
- The stability properties (ignition temperature, flammability limits, and flame velocity) are not readily available for liquid fuels, **but flame stability is often less critical with liquid fuels**.

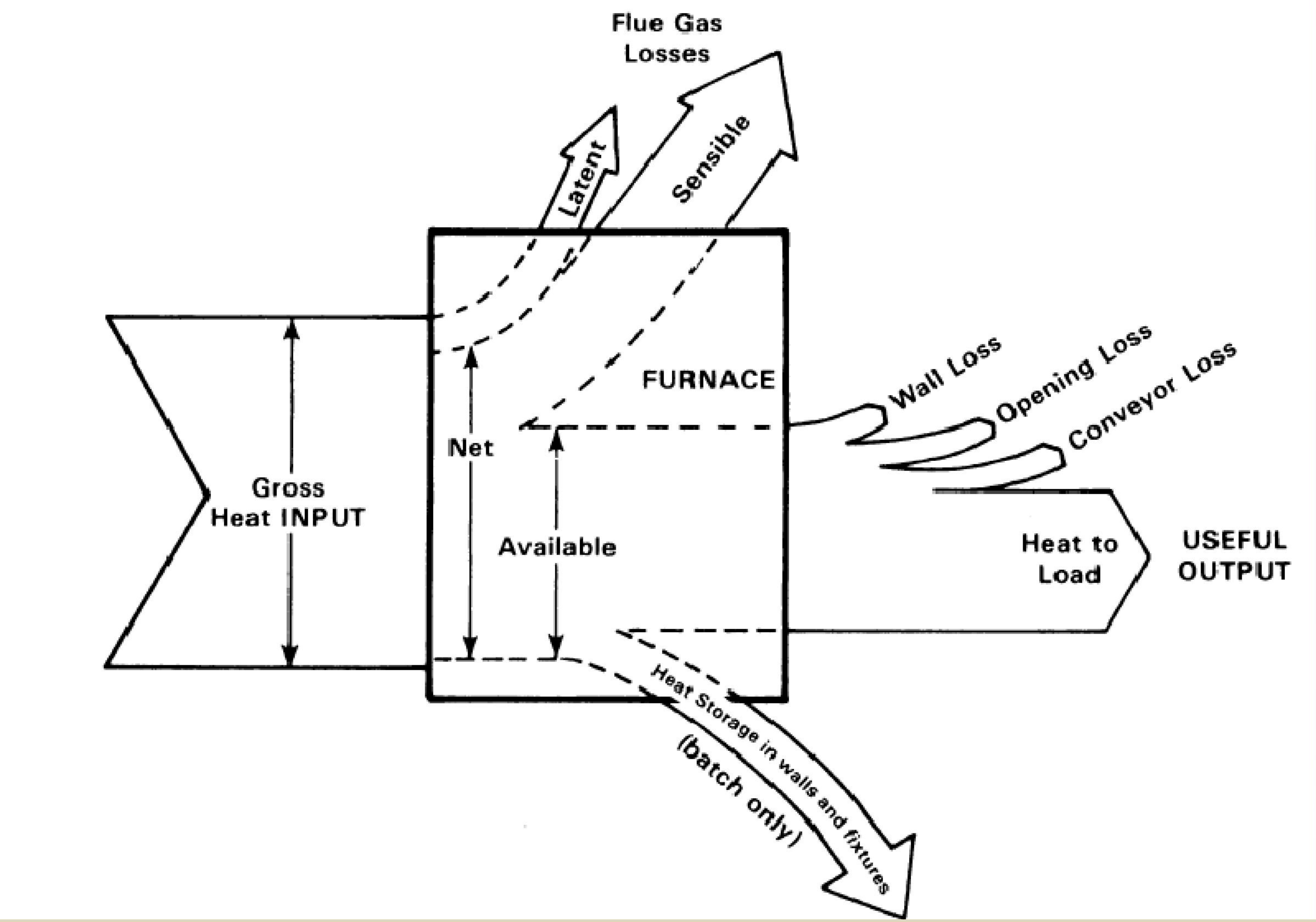
Combustion of fuels

- **Solid fuels** are frequently more difficult to burn, handle, and control than liquid or gaseous fuels.

- After initial devolatilization or release of volatile matter, the combustion reaction rate depends on diffusion of oxygen into the remaining char particle, and the diffusion of carbon monoxide back to its surface, where it burns as a gas.

- Reaction rates are usually low and required combustion volumes high, even with pulverized solid fuels burned in suspension.

THERMAL ASPECTS OF COMBUSTION



Snaky diagrams for a furnace, oven, kiln, incinerator, boiler, or heater-a qualitative and roughly quantitative method for analyzing efficiency of fuel-fired heating equipment

Calorific value of a fuel

The calorific value of a fuel :- is the amount of heat energy produced on complete combustion of 1 kg of a fuel. The calorific valve of a fuel is expressed in kilojoules per kg.

Calorific values of some fuels in kilojule per kg

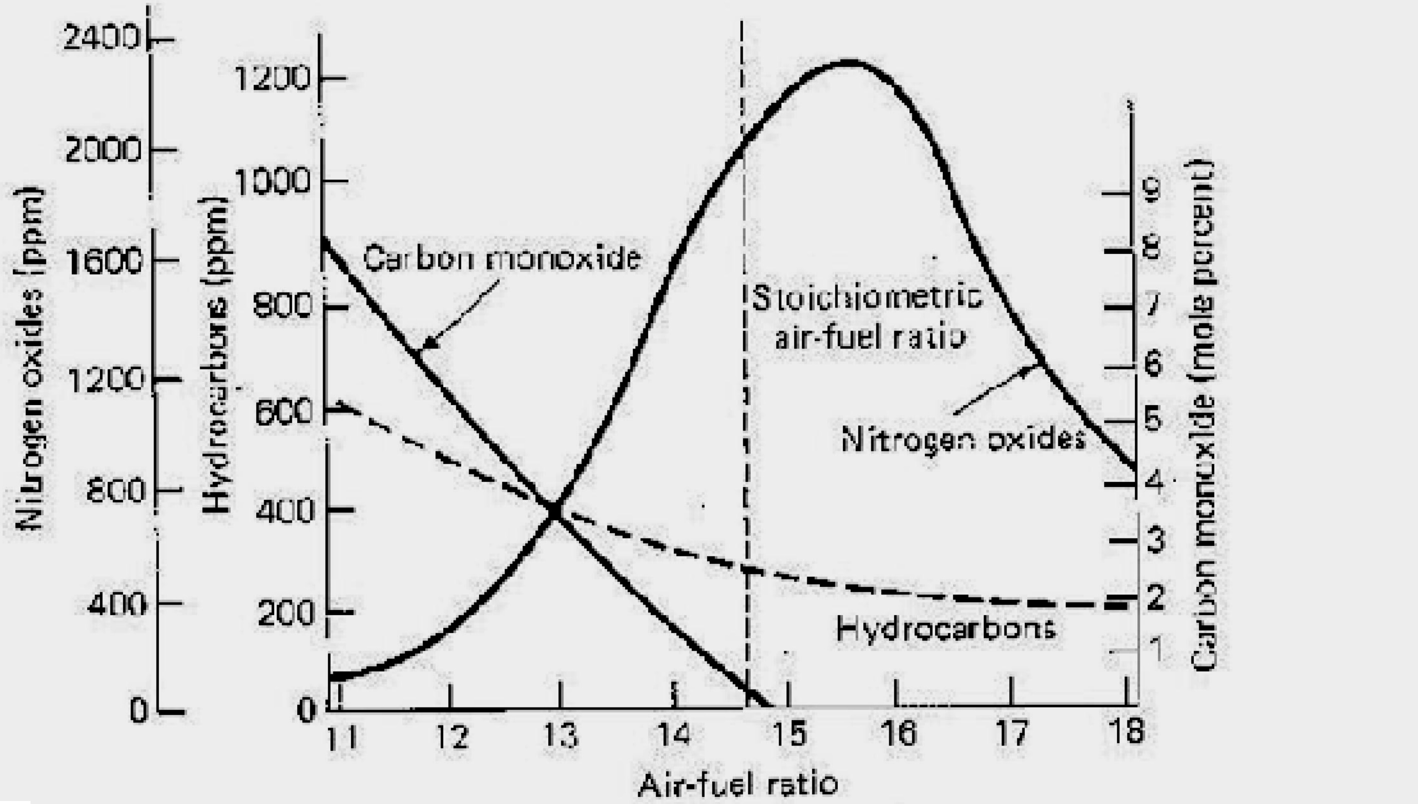
Wood	17000 - 22000
Coal	25000 - 33000
Petrol	45000
Kerosene	45000
Diesel	45000
Methane	50000
CNG	50000
LPG	55000
Biogas	35000 - 40000
Hydrogen	150000

Hydrogen has the highest calorific value among all fuels.

The functions of a properly designed fuel system device can be listed as follows:

1. To introduce desired quantities of fuel and air into a furnace to release a given amount of heat
2. To release heat in a specified heat release pattern
3. To provide stable ignition and safe operation
4. To induce proper mixing of fuel and air
5. To allow for sufficient turndown range
6. To allow for fuel and oxidant composition variations
7. To be simple in operation
8. To have low pollutant emission and minimum noise
9. To maximize efficiency

Air Pollutants from Combustion



Exhaust hydrocarbons, carbon monoxide, and nitric oxide as a function of air–fuel ratio. Source: Seinfeld, J. Atmospheric Chemistry and Physics of Air Pollution.

How do you explain the trends of the exhaust HCs, CO, and NOx as a function of air-fuel ratio?

How do you minimize NOx and CO emission?

Combustion Stoichiometry

- **Combustion in Oxygen**

$$C_nH_m + O_2 \rightarrow CO_2 + H_2O$$

1. **Can you balance the above equation?**
2. **Write the reactions for combustion of methane and benzene in oxygen, respectively.**

Answer

$$C_nH_m + \left(n + \frac{m}{4}\right)O_2 \rightarrow nCO_2 + \frac{m}{2}H_2O$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

$$C_6H_6 + 7.5O_2 \rightarrow 6CO_2 + 3H_2O$$

Combustion Stoichiometry

❑ **Combustion in Air (O_2 = 21%, N_2 = 79%)**

$$C_nH_m + (O_2 + 3.78N_2) \rightarrow CO_2 + H_2O + N_2$$

1. **Can you balance the above equation?**
2. **Write the reactions for combustion of methane and benzene in air, respectively.**

Answer

$$C_nH_m + \left(n + \frac{m}{4}\right)(O_2 + 3.78N_2) \rightarrow nCO_2 + \frac{m}{2}H_2O + 3.78\left(n + \frac{m}{4}\right)N_2$$

$$CH_4 + 2(O_2 + 3.78N_2) \rightarrow CO_2 + 2H_2O + 7.56N_2$$

$$C_6H_6 + 7.5(O_2 + 3.78N_2) \rightarrow 6CO_2 + 3H_2O + 28.35N_2$$

1. **What if the fuel contains O, S, Cl or other elements?**

2 **Is it better to use O_2 or air?**

Air-Fuel Ratio

- **Air-Fuel (AF) ratio**

$$AF = m_{Air} / m_{Fuel}$$

Where: m_{air} = *mass of air in the feed mixture*

m_{fuel} = *mass of fuel in the feed mixture*

Fuel-Air ratio: $FA = m_{Fuel} / m_{Air} = 1/AF$

- **Air-Fuel molal ratio**

$$AF_{mole} = n_{Air} / n_{Fuel}$$

Where: n_{air} = *moles of air in the feed mixture*

n_{fuel} = *moles of fuel in the feed mixture*

What is the Air-Fuel ratio for stoichiometric combustion of methane and benzene, respectively?

Air-Fuel Ratio

- **Rich mixture**
  - **more fuel than necessary**

    $(AF)_{\text{mixture}} < (AF)_{\text{stoich}}$

- **Lean mixture**
  - **more air than necessary**

    $(AF)_{\text{mixture}} > (AF)_{\text{stoich}}$

Most combustion systems operate under lean conditions.
Why is this advantageous?

Consider the combustion of methanol in an engine. If the Air-Fuel ratio of the actual mixture is 20, is the engine operating under rich or lean conditions?

Equivalence Ratio

***Equivalence ratio*: shows the deviation of an actual mixture from stoichiometric conditions.**

$$\phi = \frac{(FA)_{actual}}{(FA)_{stoich}} = \frac{(AF)_{stoich}}{(AF)_{actual}}$$

The combustion of methane has an equivalence ratio Φ=0.8 in a certain condition. What is the percent of excess air (EA) used in the combustion?

How does temperature change as Φ increases?

Formation of NOx and CO in Combustion

- ☐ **Thermal NOx**
  - **Oxidation of atmospheric N_2 at high temperatures**

$$N_2 + O_2 \leftrightarrow 2NO$$

$$NO + \tfrac{1}{2}O_2 \leftrightarrow NO_2$$

  - **Formation of thermal NOx is favorable at higher temperature**

- ☐ **Fuel NOx**
  - **Oxidation of nitrogen compounds contained in the fuel**

- ☐ **Formation of CO**
  - Incomplete Combustion
  - Dissociation of CO_2 at high temperature

$$CO_2 \leftrightarrow CO + \tfrac{1}{2}O_2$$